

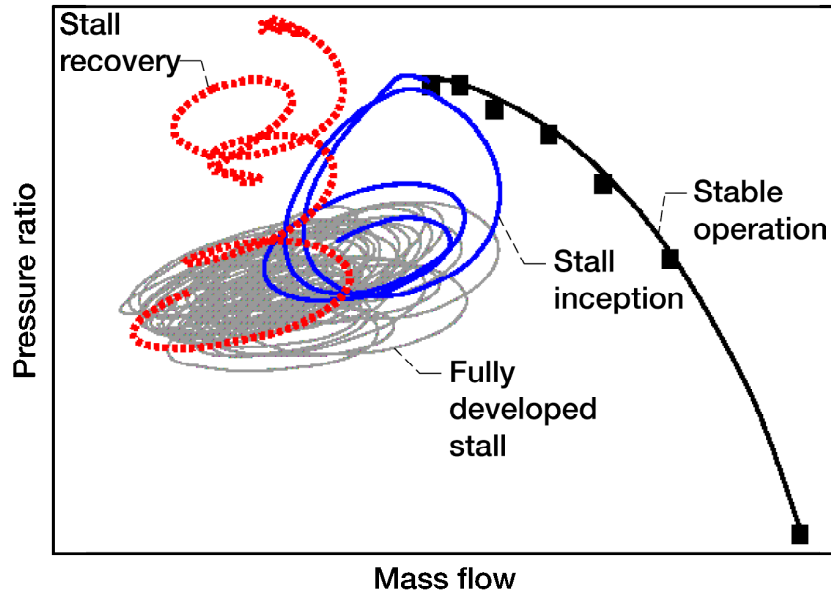
Compressor Stall Recovery Through Tip Injection Assessed

Aerodynamic stability is a fundamental limit in the compressor design process. The development of robust techniques for increasing stability has several benefits: enabling higher loading and fewer blades, increasing safety throughout a mission, increasing tolerance to stage mismatch during part-speed operation and speed transients, and providing an opportunity to match stages at the compressor maximum efficiency point, thus reducing fuel burn.

Mass injection upstream of the tip of a high-speed axial compressor rotor is a stability enhancement approach known to be effective in suppressing stall in tip-critical rotors (ref. 1) if the injection is activated before stall occurs. This approach to stall suppression requires that a reliable stall warning system be available. Tests have recently been performed to assess whether steady injection can also be used to recover from fully developed stall (ref. 2). If mass injection is effective in recovering from stall quickly enough to avoid structural damage or loss of engine power, then a stall warning system may not be required.

The stall recovery tests were performed on a transonic compressor rotor at its design tip speed of 1475 ft/sec using four injectors evenly spaced around the compressor case upstream of the rotor. The injectors were connected to an external air source. In an actual engine application, the injected air would be supplied with compressor bleed air. The injectors were isolated from the air source by a fast-acting butterfly valve. With the injectors turned off, the compressor was throttled into stall. Air injection was then activated with no change in throttle setting by opening the butterfly valve. The compressor recovered from stall at a fixed throttle setting with the aid of tip injection.

The unsteady operating characteristic of the rotor was measured during these tests using high-response pressure sensors located upstream and downstream of the rotor. The figure shows the results, where the unsteady pressure and massflow are superimposed on the steady operating characteristic. The total injected massflow was equal to 1.3 percent of the compressor flow. The solid line with no solid squares on it denotes the operating point during the beginning of throttle closure and the initial drop into stall. The gray traces denote the operating point during an additional throttle closure that occurred over the next 1200 rotor revolutions (4 sec). The dashed line denotes the recovery from stall that occurred during 90 rotor revolutions (0.3 sec) after the injectors were activated with no change in throttle setting. Tip injection not only recovers the compressor from stall, but also restores the compressor to its pre-stall level of pressure rise. In contrast, standard stall recovery schemes such as compressor bleed, stator vane actuation, or engine throttle modulation result in a loss of pressure rise across the compressor, which results in a loss of engine power.



Unsteady compressor operating point at design speed during stall inception and stall recovery. Stall recovery at a fixed throttle setting (dashed lines) occurs 0.3 sec after tip injection is activated.

References

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2. Suder, Kenneth L, et al.: Compressor Stability Enhancement Using Discrete Tip Injection. The 45th ASME International Gas Turbine & Aeroengine Congress, Exposition and Users Symposium, 2000-GT-0650, 2000.

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